THE GEOLOGY OF THE SAN FRANCISCO PENINSULA.[1]

(WITH A MAP.)

By Roderic Crandall.

(*Read January 4, 1907.*)

Introduction.

The main points to be covered in this paper will be stated in the beginning. These are:

1. A description of the terranes mapped with an outline of the petrography of each.

2. A description of the structure of the area with the resulting physiography.

3. A general discussion of five points of special interest: The age of the non-crystalline sedimentary rocks of the Franciscan or Golden Gate series; the origin of the Merced series; the origin of the jaspers, serpentines and metamorphic schists. In the general discussion it will be realized that this is the application of information from work done by others to local problems, in an endeaveor to throw any light possible upon some of the complex problems of the Coast Range geology.

The actual field work has been much facilitated by the good maps available. On the whole area the map of the U. S. Geological Survey has been found excellent, the topography of this map being mostly the work of the U. S. Coast and Geodetic Survey. In the city proper the map of Britton & Rey was found very good for street location. The photographs with the exception of three, two of the anticline near San Bruno point and one of the relief map of San Francisco, are the work of Mr. Robert Moran. The three excepted were taken by Mr. Berton Crandall.

[1] A thesis for the degree of A.M., presented to the Department of Geology of Stanford University, April, 1907.

II. Geological Terranes.

There are six geological terranes represented on the San Francisco peninsula.

I. The Montara granite.
II. Franciscan or Golden Gate series.
III. Merced series (Pliocene).
IV. Pleistocene and recent including the sand dunes derived from the Pleistocene.
V. Serpentines.
VI. Igneous intrusives other than peridotite.
VII. Schists.

I. The Granites.—The Montara granite does not properly belong within the area mapped, but it deserves mention in this connection because of its direct relation to the Franciscan series and the problem of the age of the latter. It belongs to the oldest rocks that appear in the Coast Ranges but is considered to be younger than the crystalline limestones and schists that occur exposed further south in these same ranges. The age of the schist and limestone is unknown and the age of the granite is likewise unknown further than that it is older than the Franciscan series, and is considered by Dr. Fairbanks to be older than the granite of the Sierras, which is intrusive in the upper Jurassic sedimentary beds.

II. The Franciscan Series.—The Franciscan series, which is the one of chief interest, rests upon the eroded surface of this granite as exposed on the northwest end of Montara Mountain near Devil's Slide. The lowest beds of the series are conglomerates containing boulders of granite that lie directly on the igneous rock. The petrographic evidence shows that the sandstone is derived mainly from the erosion of this or some similar igneous rocks, and is necessarily arkose.

The Franciscan series proper consists of five beds in the following order.

1. *Coarse Conglomerate* containing large boulders of granite.

2. *The San Pedro Shales.*—These are thinly bedded black shales having a thickness of approximately four thousand feet. This sec-

tion is exposed in the cliffs north and south of San Pedro Point for which they are named. The shale is very similar throughout, being grayish black, close grained and hard. It is in thin layers

FIG. 1.

San Pedro Point, showing the beds called San Pedro shale dipping northeast.

varying in thickness from an inch to twelve or fourteen inches and occasionally interbedded with fine and coarse grained sandstones that grade into granite-bearing conglomerates which are not persistent. The beds weather into oval forms, the outer surface of a lump often being marked with ridges that define the oval forms into which the shale breaks.

3. *Limestones.*—Overlying this shale series is a limestone partially crystalline in general, and wholly so in places, but more commonly interbedded with jasper layers approximating an inch in thickness. This limestone occurs in Calera Valley where it forms several small hills, and it continues intermittently toward the southeast, the largest area being on Cahill Ridge. No work was done upon this limestone but it has been described by Professor Lawson

as showing, microscopically, the presence of many foraminifera and is called by him foraminiferal limestone.[1]

4. *San Bruno Sandstone.*—Above the limestone come the most characteristic beds of the series. These are shales, and sandstones, which occasionally have coarse conglomerates interbedded with them. With the shales are also large accumulations of pyro-clastic materials which are confined to a fairly well defined horizon just below

FIG. 2.

San Pedro shale beds dipping southwest; a point just north of San Pedro Point.

the jasper beds. In mapping, these volcanic tuffs have not been differentiated from the rest of the series. It is the weathering of these tuffs that gives rise to the most of the numerous and varied forms of metamorphic rocks, which, in the field, have been called greenstones.

The larger part of this horizon is made up of sandstone proper, which, when fresh, is a hard, blue gray rock, generally showing but few bedding planes, the dip being only discernible where thin beds of shale are present.

[1] 15th Ann. Rept. U. S. Geological Survey, p. 405.

This phase of the series is well exposed in the large quarries in the city of San Francisco. One just northwest of Ocean View, and another about one half mile south of Ocean View show especially good sections. The black shales that occur in this sandstone are well exposed in the cuts made at Visitation Point and north of there, along the line of the new bay shore road of the Southern Pacific railway.

The top of this sandstone series is a few hundred feet of sandstone that is very generally characteristic wherever found. The noticeable thing is the form in which it weathers, a soft light yellowish gray rock with pink spots throughout it. The persistence of this character of the rock has been noted at the several places where it is exposed, even when the exposures are some distance apart. It is best shown about half a mile east of the Cliff House, but specimens from the southwest side of the San Bruno mountains, and Sawyer's Ridge near San Francisco, and from Alum Rock canyon and San Felipe Valley, in the Mount Hamilton region, are macroscopically identical. It is to be noted here that in all four of these places the horizon is the same, that is directly under the lowest bed of the red jasper.

5. *Jaspers.*—The next group of beds in the Franciscan series is the jasper. This consists of three beds, which in this area, have been mapped separately. At the bottom of the group is the lowest jasper. This is a bed approximating five hundred feet in thickness. Lying upon this are sandstones, shales, tuffs, and lignites with an approximate thickness of four hundred feet. Over this is the upper bed of jasper which is at least a thousand feet in thickness.

These jaspers are thinly bedded flinty layers, varying from a fraction of an inch to an inch in thickness, and very persistent in character. They are dull reddish, stained with iron oxide, but varying in places to green, white and other colors more locally. In places the jaspers are traversed by white veins of quartz or calcite.

6. *Telegraph Hill Sandstone.*—The top of the Franciscan series, as exposed at San Francisco, consists of eight hundred or a thousand feet of sandstones and shales that is very similar to that underlying the jaspers. This sandstone is particularly well exposed in Telegraph Hill where it is quarried extensively. The shales of this

series are also exposed here but are best shown where Second street has been cut through Rincon Hill, from Mission street eastward. In this part of the series the volcanic tuffs are also to be seen but only in small exposures.

So far as is known the Franciscan series is a unit, and though the complete section cannot be crossed continuously, owing to structural features, outside of the unconformity between the two jasper

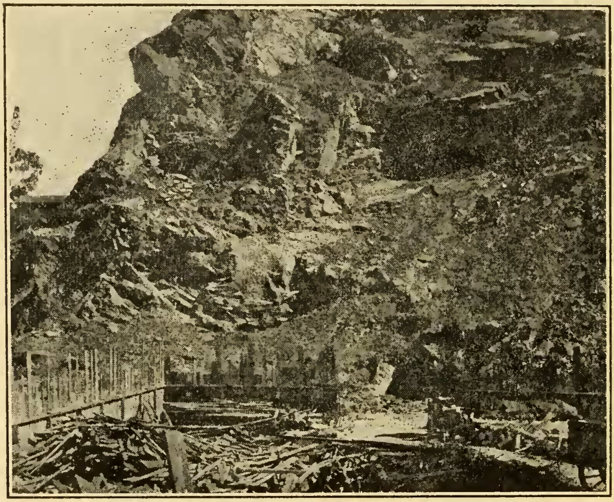


FIG. 3.

Jointing planes in massive sandstone exposed in a quarry on the northeast side of Telegraph Hill.

beds, which is regarded as local, the series is here geologically a continuous one.

The Franciscan series as a whole is much fractured, folded and metamorphosed, even more so in other regions than on the San Francisco peninsula. This deformation seems to have been general and the unaffected regions are smaller and more local than the affected ones.

The effects of this deformation are shown in the present state of the beds. The peculiar shapes into which the San Pedro shales break are due to the movements to which they have been subjected. The most noticeable effect in the sandstones is the many joint planes which in an open quarry obscure the original bedding planes. Professor Lawson has attributed these joints to weathering but their occurrence in fresh rock after the same fashion leads to the belief that they are of dynamic origin, though they are much more evident in the wethered beds. In the open quarries, planes along which

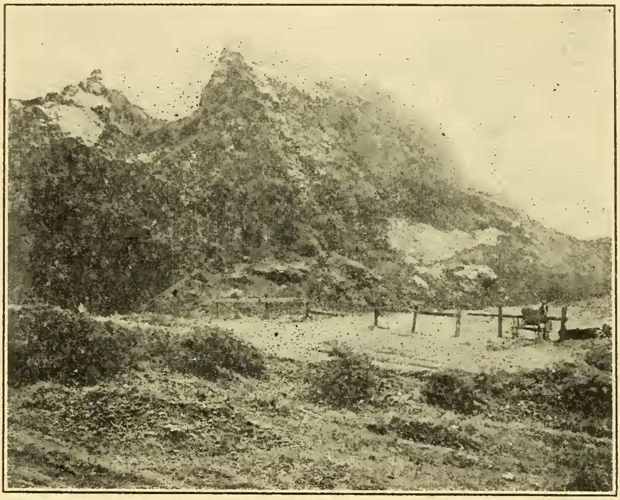


Fig. 4.

Slickensided faces in jasper, shown at a quarry on Lobos Avenue near the ocean.

slipping has occurred and small faults from a few feet to a hundred feet, may be observed crossing each other at varied angles and in many directions. In the small faults the sandstone may be seen altered to a thickness from three to ten inches on either side of the fault plane. Secondary silicification is widespread in these sandstones, giving rise to barren quartz veins in places, some of which were the cause of the gold mining excitement on San Bruno mountain some years ago.

The tuffs also show marked effects of regional disturbances, resulting in the formation of dark green, hard, compact rocks, which were termed greenstones in the field until their true character was ascertained. Examples of this rock may be seen in the small islands along the cliffs of the Golden Gate, at Silver Terrace hill and at Mussel Rock.

The jaspers more than any other rocks, show the result of crushing in the contortions and wrinklings of their layers. They seem to be beds of great elasticity, that bend and twist without breaking.

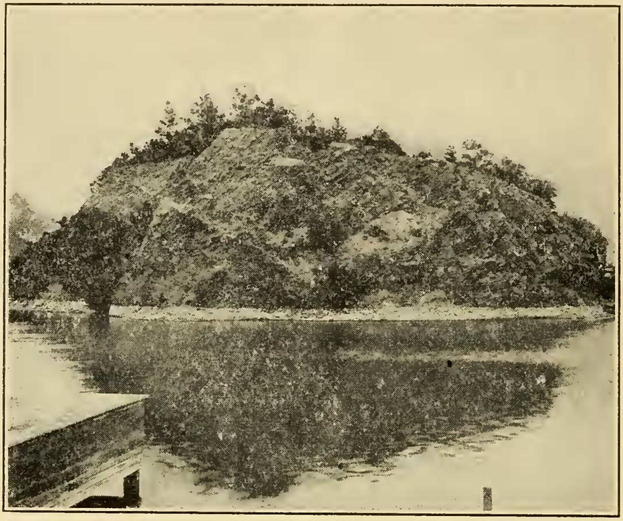


FIG. 5.

Local folding and faulting of jaspers at Stow Lake, Golden Gate Park.

In nearly every place where they are exposed they show either parallel successions of close folds, or wavy structure, which is particularly well emphasized by their thin bedding.

PETROGRAPHY OF THE FRANCISCAN ROCKS.

Sandstones.—The sandstone, in the hand specimen, when fresh, is a bluish gray rock; when weathered it is a dull yellowish brown. In the field this sandstone is characterized by two of its constituents, the small flakes of shale and the presence in certain localities of considerable amounts of brown mica. Slides of this rock from various places are very similar except for the presence of mica, and in nearly all cases show that it is sandstone derived almost entirely from the weathering of an igneous rock—in other words it is an arkose.

The grains are small and angular rather than rounded, set widely apart in a large amount of cementing material. This cementing material seems partly silicious and partly ferruginous but at times it is calcareous. Most of the grains appear to be quartz, but when optical figures were attempted, on various sections, biaxial figures were obtained showing a portion of them to be feldspars instead of quartz. Plagioclase is present in all the slides and is noticeable by its twinning. In one slide a large angular rock fragment was observed which was composed of quartz and plagioclase. The extinction angle of this plagioclase gave about 18°, placing the feldspars with the acid labradorites or near the oligoclase. Dr. Becker in his monograph on the coast quicksilver deposits, remarks on the uniformity of this arkose throughout the state. He says the typical feldspar is oligoclase with occasionally a more basic one, quartz and orthoclase being in about equal amounts.

One point of interest in connection with this sandstone is the presence of feldspars. As the experiments of M. Daubrée show that pulverized feldspars change to kaolin very rapidly in the water, the conclusion is that these rocks are shallow water deposits.

The presence of the orthoclase and oligoclase with quartz, in the slides, taken with field relations between this sandstone and the Montara granite leads to the conclusion that this granite may be part of this land mass, though it is not necessarily true that this sandstone is all formed from the Montara granite, but from a granite that possibly underlies the whole Coast Range and of which this is a part.

Small fragments of brown mica are often present, and little, long flakes of black shale that appear blue black in ordinary light, but which are not affected by polarized light.

Quartz appears throughout the rock in small veins, traversing it in all directions. These veins are newer than the mass of the rock, but they were formed before the dynamic movements took place, for they give the same wavy and banded extinction that all the quartzes and feldspars do in the main rock mass. The secondary quartz shows fine aggregate texture with each little crystal of the aggregate having its own position of extinction. Secondary quartz of this nature is seen in nearly all of the rocks of the Franciscan series.

Calcite, another secondary mineral, is present and is later than the quartz, cutting through the rock regardless of previous fractures. The extinction of the calcite is not wavy, due to the fact that it is later than the period of movement.

Slides were made of sandstone from the specimens taken from within four inches of the contact of the serpentine and sandstone at the Presidio and the Potrero. No metamorphism was observed, except for a slight difference in the cementing material, showing that no contact metamorphism has taken place here, even at so short a distance from the serpentine. A slide made from sandstone taken from the face of a small slip zone in one of the open quarries, shows the results of movement in this rock. The cementing material had been changed to a fibrous green mass that was not affected by polarized light. The quartz was all recrystallized into the fine aggregate texture mentioned before, but in some cases the original form or outline of the sand grains could still be seen.

This is interesting to show the amount of metamorphism produced by the intrusion of a large mass of periodotite, and by movement resulting in a small fault.

Tuffs.—The much weathered tuffs appear as dark green or much iron stained crumbly beds, and are well characterized by their popular name of "rotten rock." They are much broken up beds that can easily be dug into with a hammer, and possess no visible bedding planes unless associated with sandstone or shale. This is the form of the rock under ordinary weathering but when metamorphosing agencies have acted upon it, it becomes a hard green rock, with much quartz and has the appearance of a metamorphosed jasper.

Slides were made from this tuff from Baker's beach, Point Lobos beach, Silver Terrace hills, Potrero and several other localities, the best specimens being obtained from Silver Terrace.

At the last named place the tufaceous nature of the rock can be plainly seen in the weathered specimens. In a quarry near Silver avenue and First street the relation of the fresh to the weathered rock is seen. Here there appears to be a dike of green rock intruded into the tuff, but a microscopic examination shows the apparent green dike and the brown tuff to be the same. In a street cut on Railroad avenue near Nineteenth avenue the cause of the metamorphism of the tuff is plainly seen in the presence of a dike of diabase which appears to have a width of at least one hundred feet. Further south on Railroad avenue the presence of much broken and contorted jaspers determine the proper horizon of the tuffs.

The specimens for this work were taken from the new Southern Pacific railway tunnel through the hill on Railroad avenue.

In a slide the main part of the rock is a dark green mass that does not react to either ordinary or polarized light. Tests with hydrochloric acid show that it is mainly amorphous silica stained with iron. Set in this groundmass are clear irregular shaped crystals some of which are quartz and some are feldspars. Plagioclases showing banded twinning and wavy extinction are present and the measurement of extinction angles, though not entirely accurate, gave about 18°. Rock fragments were seen in one slide and these were micro-perthite, intergrowth of orthoclase and albite. This with the presence of the untwinned feldspars led to the conclusion that the twinned feldspars belong to the albite group, although the extinction angle is rather high, due perhaps to inaccuracy in measuring a feldspar with wavy extinction. No large amount of ferromagnesian minerals is present, small amounts of a brown mica being the only ones observed.

The quartz of each grain present has been recrystallized into minute aggregate texture, the average size of the new grains being about .02 mm. in diameter. Small patches of the same dark blue shale are present that were noted in the sandstone, as are also secondary quartz and calcite veins.

This tuff that has just been described is from the Silver Terrace hills; those from Baker's beach region show the presence of two other minerals, chlorite or a chlorite-like mineral and irregular masses of pyrite.

The chlorite is present in long fibrous seams and irregular patches. It is strongly pleochroic from dark green to yellowish green. In one slide this mineral appears along a seam in the rock in the form of fibrous spherulites ranged on both sides of the seam, and growing toward the center. Under cross nicols it shows anomalous colors, Berlin blue, yellow and brown, with a wavy extinction that is approximately parallel.

According to Rosenbusch, chlorites are common minerals as secondary products in altered tuffs, being derived from the aluminous members of the biotite and phlogophite micas, pyroxenes and amphiboles. Just what minerals the chlorite in these tuffs was developed from is indeterminable from any slides made, but it represents the presence of some of the ferro-magnesian minerals previous to metamorphism.

The presence of albite, microperthite, orthoclase and quartz places the tuff with the acid group, but not definitely.

This tuff shows three periods of metamorphism: first, the formation of pyrite and chlorite; second, the introduction of the secondary quartz veins, which show recrystallization and wavy extinction, and which have cut through the chlorite; third, the introduction of veins of calcite that do not show wavy extinction and which are later than the quartz.

Jaspers.—The hand specimens of the jasper need little description as they are already well known. Very little petrographic work was done upon them but a resumé is here given of the results of the examination made by Dr. Hinde.[1]

Sections were made from the chert from Angel Island and from the Buri-Buri ridge, San Mateo county. The radiolaria appear as rounded outlines, with diameters of .055 mm. to .3 mm., set in a matrix of silica. The structure is not retained, the walls having graded into the silica matrix. In general the silica of the cast differs from that of the main rock mass, which shows a minute aggregate form.

All the forms were poorly preserved, making the exact determination unsatisfactory, and specific correlation impossible with other known radiolaria. In general the types resemble those from the Cretaceous and Jurassic of Europe. Dr. Hinde has given a partial identification of certain species, and plates illustrating these accompany his paper.[2]

III. Merced Series (Pliocene).—The Merced series is well exposed along Seven Mile beach, presenting a measured section

[1] The Radiolarian Chert of Angel Island, Bulletin Department Geology, University of California, I, No. 7, p. 235.

[2] *Loc. cit.*, p. 240.

over a mile in thickness. The beds are only partially consolidated except locally. The series consist mostly of sands and clays bedded from a few feet to over a hundred feet in thickness. Certain thin conglomerate layers are much harder and more resistant than others; these consist of jasper pebbles and broken shells. This hard conglomerate is well exposed at Mussel Rock and along the ridge southeast of there, lying along and near the Franciscan rocks. There are dark or almost black clay beds in the series and these are the ones that are most fossiliferous. As the upper part of the section is approached the beds are softer and more sandy. There are a few small layers of lignitic material and in the cliffs just south of the Life Saving Station there is a layer of white volcanic ash. Along the cliff this layer of ash has a fairly constant thickness of ten or twelve inches.

Dr. Ashley has described these beds more thoroughly and has given their identification in his paper.[1]

IV. Post-Pliocene.—Above the Merced series lies the Pleisto-

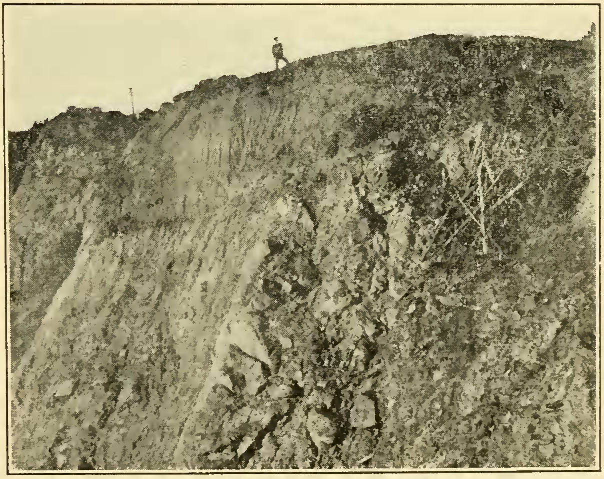


Fig. 6.

Pleistocene and recent deposits overlying the serpentine of the Presidio sill.

[1] Neocene Stratigraphy of the Santa Cruz Mountains, Proc. Cal. Acad. Sci., Series 2, V, 312.

cene, consisting of a thickness of perhaps one hundred feet of partly consolidated clay. Dr. Ashley mentions a thickness of two hundred feet south of Mussel Rock. In the area mapped the thickness of the Post-Pliocene beds was difficult to determine but is probably not over one hundred feet.

The question of the conformity or unconformity of the Pliocene and Pleistocene is one that is yet to be decided and is not evident in this area. No paleontologic work was attempted upon these beds.

V. Serpentines.—In the city the serpentines form a prominent terrane; the best exposures for study are in the large hills at the Potrero. The serpentine is found in several places, and is always

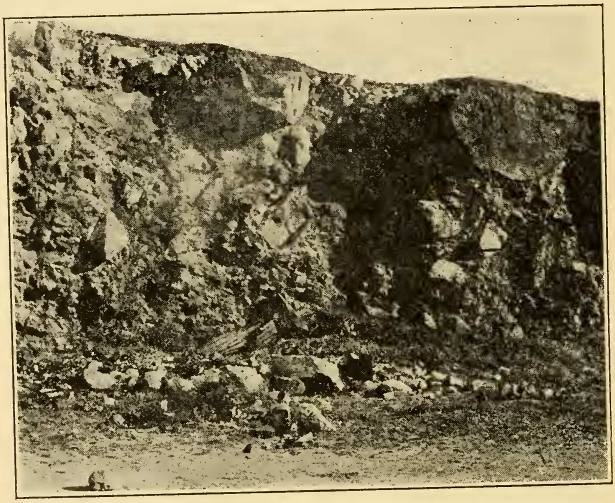


Fig. 7.

A conglomeratic effect in serpentine as exposed in a quarry on Potrero Ave., near the railroad.

characterized by the blue green appearance, and by a lack of soil and vegetation over the surface. In the quarries of the Potrero the original peridotite rock may be seen. This appears as large black boulders in the serpentine, giving the appearance of a coarse conglomerate. Each of these boulders is separate from the others and coated with from one to many inches of slickensided serpentine. This shows the breaking up of the peridotite mass and the large amount of movement that has taken place, due to the increase in volume in the formation of serpentine.[1]

The peridotite is the fresh facies of the serpentine, and has been shown petrographically to be the rock from which the serpentine proper is derived. The other or slickensided facies of serpentine is the one with which nearly everyone is familiar. It is blue to green in the hand specimen, soft and smooth to the touch. It flakes roughly, giving always new slickensided faces showing that there have been movements in every little particle of the rock. There are occasionally varying streaks of a hard brown rock that seems different from the main mass but which petrographically is just the same.

Associated with these serpentines are small veins of magnesite, some of it of the fibrous variety, and some hard and compact. Another rock that is found with the serpentines has been termed "silicious carbonate sinter" by Professor Lawson.

This material is a weathered product of the serpentines. It is a hard, light-colored rock showing lines of silicification throughout. It is believed to have been produced by a leaching of the magnesium, in the form of a carbonate, from the serpentine, with a simultaneous redeposition of the silica present as amorphous silica, and more or less stained with the iron from the original rock.[2] The magnesium leached out probably goes toward the formation of the magnesite veins common in the serpentine. Rock sections show but little except the lines of silicification, as the amorphous silica does not react in the ordinary or polarized light.

Petrography of the Serpentines.

The petrography and a few chemical analyses of the serpentines that are available are of much interest.[3] The description of two facies of the serpentine will be given, the massive facies and the slickensided facies.

[1] G. P. Merrill gives 33 per cent. as the increase of volume due to formation of serpentine by the hydration of olivine.

[2] Knopf, A., An Alteration of Coast Range Serpentine, Bulletin Department Geology University California, IV, No. 18, p. 425.

[3] Dr. Palache has described the serpentines in his paper on the lhezolite serpentines of the Potrero. Bulletin Department of Geology University California, I, No. 5, p. 235.

Massive Facies.—Fresh specimens of the massive facies were taken from the Potrero and the Presidio.

From the Potrero no sections were obtained in which serpentine was not present. Other constituents or original minerals present in the peridotite are as follows: orthorhombic pyroxene enstatite, monoclinic pyroxene diallage, olivine, magnetite, and chromite. These constituents give the serpentine the name of lhezolite, the original rock being a peridotite.

The largest constituent of this rock appears to be the pyroxene diallage. The crystals show no definite form but are in long irregular shapes, possessing marked cleavage in the long direction. Basal sections occasionally show the parting characteristic of diallage. The relief is medium and the crystals are colorless in ordinary light. Under cross nicols the colors are high, most commonly upper first and second order. The extinction angle varies with the different sections from 18° up, the largest angle measured being 48°, the commonest about 43°.

Enstatite, the orthorhombic pyroxene, occurs in lesser quantities than the diallage and is indistinguishable from the diallage in ordinary light, the relief, color and form of the sections being similar.

Under cross nicols the colors are low, blue grey of the first order in a slide of proper thickness. Being orthorhombic the extinction is parallel and so may be distinguished from the diallage.

In one section fine multiple twinning was observed in the enstatite; the extinction was almost simultaneous for the two sets of lamellae, making it not especially noticeable. The lines of twinning made an angle of over 30° with the direction of extinction, but because of lack of similar sections the face of twinning was not determined. Rosenbusch remarks that the twinning of enstatite is not common. Both the pyroxenes showed in most of the slides with serpentine formed through them with lattice work effects.

Olivine is present only in small irregular grains wholly surrounded by serpentine due to its having weathered faster than the pyroxenes.

In ordinary light it is clear and colorless and is distinguished from the pyroxenes by its higher relief and lack of cleavage. In polarized light its colors are high, being upper second in general. Groups of these olivine grains situated together would often extinguish simultaneously, showing that the original crystals of this mineral were quite large.

Magnetite in black patches and chromite in brownish black masses were present, scattered through the serpentine and as inclusions in the diallage.

The pyroxenes showed marked wavy extinction, due to the amount of pressure and movement to which they have been subjected.

The serpentine appears yellowish and greenish in ordinary light and surrounds the grains of olivine and in lattice work forms through the pyroxenes. It seems stained with iron to a considerable extent. In polarized light it is blue grey with a felted appearance and compensatory extinction.

Slickensided Facies.—The slickensided facies is similar to this except that none of the original minerals remain, the serpentine derived from the pyroxenes being the same as that derived from the olivine.

ANALYSES OF SERPENTINE.

Locality.	Presidio.	Angel Island.	Mt. Diablo.
SiO_2	39.60	42.06	36.57
Cr_2O_3	.20		.33
Al_2O_3	1.94	} 2.72	95
Fe_2O_3			7.29
FeO	} 8.45	2.88	.37
MnO			.10
NiO			.31
CaO			.14
MgO	36.90	39.53	40.27
K_2O			trace
NaO			.31
H_2O above 100°	12.91	12.04	12.43
	100.00	99.23	99.07
Analyst.	Dr. Easter.	F. L. Ransome.	Dr. Melville.

The fresh facies of the peridotite from the serpentine mass of the Presidio gave sections that showed the presence of no serpentine at all. There were two main minerals present with slight amounts of the same accessory minerals, as seen at the Potrero. Diallage and enstatite, the same as described from the Potrero, are present, the last named mineral in subordinate quantities. No olivine was found at all, making this rock a true pyroxenite. That the main mass of the serpentine of the Presidio is not derived from a pyroxenite will be seen from the chemical analyses following.[1]

Analyses.—There is a marked similarity between the analyses of the serpentine from three distinct localities.

Turner mentions the gradation from peridotite to pyroxenite in the serpentine of Mt. Diablo. The analysis of the Presidio serpentine shows it to be an olivine bearing rock, so that the pyroxenite may be considered a local variation in the main peridotite magma.

VI. Igneous Intrusives.—The igneous intrusives cut the jaspers, sandstones and the associated serpentines of the Franciscan series. They consist of several closely related varieties.

The most important of these intrusive rocks occur in the Potrero, where they are intruded in the serpentine. Of this particular

Fig. 8.

Remnant of a diabase dike intruded into the serpentine of the Potrero sill.

intrusive there are two facies: hypersthene diabase, and hornblende diabase or epidorite. The others of these intrusives from elsewhere than the Potrero are hornblende diabase, amygdaloidal diabase and

[1] These are taken from a paper of H. W. Turner, Journal of Geology, VI, 487.

hornblende diorite. The hand specimens are all more or less alike —hard green rock of close texture, only occasionally varying to a coarse grained rock in which the plagioclase and ferro-magnesian minerals are easily distinguishable with a hand lens. These will be described in the order given.

Petrography of the Igneous Intrusives.

Hypersthene Diabase.—The hypersthene diabase is the freshest rock of the series, and has the following constituents: hypersthene, malacolite, labradorite, hornblende, magnetite and ilmenite. The orthorhombic pyroxene, hypersthene, is present in small quantities. It is reddish, with a high relief, the pleochroism being fairly strong from red to greenish. The ray $\mathfrak{a}$ is red and the ray $\mathfrak{c}$ green. This occurs in large irregular prisms without any definite boundaries.

The hypersthene is characterized by parallel extinction. Around the border may be seen the growth of fibrous hornblende as in the malacolite. Some of the crystals showed a dark appearance due to the presence of small black rods of an unknown mineral. Besides the hypersthene are large irregular shaped crystals of a colorless augite, probably malacolite. In ordinary light it is clear and colorless with a medium relief. Under cross nicols the interference colors are about orange of the first order and the extinction angle is 45°. Twinning was observed.

The interesting thing in connection with the hypersthene and the malacolite is the derivation of secondary hornblende. Crystals of this colorless augite show the growth of pleochroic hornblende all about the border, noticeable in ordinary light, but in polarized light the hornblende has much higher colors. The cleavage of the hornblende is parallel to that of the augite but is more sharply marked. In a crystal with secondary hornblende of this character the extinction angle of the hornblende was 11° while that of the augite was 43°.

The hornblende is in crystals that do not show their derivation. It is in irregular allotriomorphic patches with a greater length in the direction of the cleavage. The pleochroism is from yellow to yellowish green to dark green, corresponding with the axes, $\mathfrak{c}$, $\mathfrak{b}$, $\mathfrak{a}$, with an absorption scheme $\mathfrak{a} > \mathfrak{b} > \mathfrak{c}$. The extinction angle, $\mathfrak{c} : c' = 17°$.

The texture is typically ophitic, the feldspars are long and lath-shaped and idiomorphic with regard to the other minerals. Twinning is common and measurements of extinction angles in sections of equal illumination gave 44°, placing them between labradorite and anorthite. The feldspar shows wavy extinction in all cases.

Ilmenite is present in black irregular patches surrounded by the derivative mineral leucoxene. The magnetite shows borders of thin red translucent hematite. These both occur as inclusions in the other minerals, feldspars and pyroxenes.

Hornblende Diabase.—The hornblende facies of the hornblende diabase does not show any hypersthene or malacolite, but only hornblende, idiomorphic feldspars and the accessory minerals magnetite and ilmenite. Since we saw in the previous description that the hornblende was derived from the hypersthene and malacolite, then in this rock we may consider all the hornblende as secondary, making the rock a true epidiorite.

At a certain outcrop on the top of the Potrero hills, just east of the end of Twenty-fourth and near Rhode Island streets, schistose structure is developed so that the hand specimen shows it quite plainly. In a section this schistosity is not quite as noticeable, but the results of pressure are evident. There is a new mineral, some blue soda-bearing amphibole, developing in long, slender, fibrous needles around the edges of the hornblende. This mineral is considered to be glaucophane, but owing to the minute size of the crystals no optical tests were attempted. In a section of hornblende that is pleochroic from yellow to green, the glaucophane is pleochroic from colorless to blue.

Intruded in the tuffs of Silver Terrace is a dike of hornblende diabase or epidiorite. The texture of this rock is ophitic and the constituent minerals are hornblende and labradorite feldspars, with the accessory minerals, ilmenite and magnetite, as described in the hornblende diabase from the Potrero. Three secondary minerals are present, quartz and intergrowth of epidote and clino-zoisite. The quartz is in fine seams with the usual aggregate texture. The epidote and clino-zoisite occur in long fibrous or columnar aggregates. In the seams the columnar texture is most common. The crystals are small and colorless but not clear and in ordinary light the two minerals are indistinguishable. In polarized light the epidote shows grey colors of the first order but the clino-zoisite shows upper first and second order colors. These minerals are plainly secondary but whether they are derived from the alteration of plagioclase is not apparent. When these veins are cut at right angles to the columnar length of the epidote crystals, minute cross sections are seen. These aggregates are composed of such small crystals that the compensating extinction gives the whole section a grey appearance that does not change in polarized light, with a low power objective.

Amygdaloidal Diabase.—From the north side of Visitation Valley two outcrops in place give specimens that, though badly weathered, show hornblende and feldspars. One of these rocks shows the hornblende going to chlorite in most of the slides. The chlorite is green and yellow, with a similar color in polarized light. Titanite is present in this rock in rounded grains showing rough relief and irregular cleavage cracks. In polarized light the interference colors are third order and higher, with an extinction angle that is not consistent. Near the south side of the entrance to Visitation valley is an iron stained rock that looks like a weathered conglomerate in the field. Sections of this show it to be an amygdaloidal diabase. The texture is ophitic in the lath-shaped feldspars in a groundmass of allotriomorphic hornblende. A few large crystals of feldspar occur, none of which show twinning, though most of the small ones do. The extinction angles obtained were 18°, placing them near the acid end of labradorites. The hornblende has large cavities filled with calcite mainly, but chlorite and some iron mineral are present also. The chlorite is green but non-pleochroic; in polarized light it shows blue and brown. The iron mineral is a dark reddish brown with a slight metallic lustre.

Hornblende Diorite.—A specimen of rock from the southwest side of the San Bruno mountains shows hornblende and plagioclase but without ophitic texture. The hornblende and plagioclase are the same as those already described, but it contains two new secondary minerals, spinel and titanite.

Spinel is present in large quantities, in rounded irregular grains with high relief and rough surface. Being an isotropic mineral it remains dark under cross nicols.

Titanite is present and appears somewhat similar to the spinel in ordinary light except that it is very faintly pleochroic from colorless to yellowish brown. Under cross nicols it may be distinguished from the spinel by its high interference colors. In this rock much of the hornblende has altered to chlorite, the latter being present as pseudomorphs after the former. It is pleochroic from yellow to green and hardly distinguishable from the hornblende in ordinary light. Under cross nicols, the hornblende shows second order colors, while the chlorite is greenish or blue with varying extinction. This is more clearly exemplified in the rock of the north side of Visitation Valley than in this one.

VII. SCHISTS.—The schists are all of a blue amphibole (glaucophane) variety. There are various grades from a schistose sandstone to a fine glaucophane rock.

Typical of this group is a schist from one mile east of Baker beach along the Strait. It shows nothing but fibrous masses of pleochroic blue amphibole, without any other minerals. The hand specimen is soft, blue, talcose looking rock, that might easily be mistaken for serpentine, but there was no serpentine present in the slides. This rock may be an altered clay shale.

PETROGRAPHY OF THE SCHISTS.

Basic Glaucophane Schist.—From the beach along the Strait a mile east of Baker beach come two other schists, one basic the other acid. The basic schist is a very dark rock and does not show its schistose nature. The slide contained the following minerals: hornblende, glaucophane pseudomorphed after hornblende, lawsonite, pyrite, and ilmenite. The hornblende was present only in remnants, the main part of the crystals being glaucophane. The pleochroism of the hornblende was from yellowish green to dark green but much mantled by the strong blue and violet of the glaucophane.

The elongation of the glaucophane was parallel to $\mathfrak{c}'$. The pleochroism was from colorless to violet, to blue, with an absorption scheme $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$. The extinction of the glaucophane varied only a few degrees from parallel while that of the hornblende in the same crystal was about 13°.

Lawsonite is present in rectangular prisms with elongation parallel to c′. In ordinary light it is colorless and non-pleochroic, the relief is fairly high, with a slight cleavage in the direction of elongation. In this section the colors are upper first and second order, but in basal sections the colors and relief are not so high. The lawsonite is idiomorphic with regard to the hornblende and glaucophane.

Pyrite and ilmenite occur in irregular masses as inclusions in the other minerals. Secondary quartz veins traverse the sections.

Considering the minerals now present and the texture of the rock it seems probable that it is an altered form of hornblende diabase, the glaucophane having developed from hornblende and the lawsonite having been formed by hydration of basic feldspars.

From this same locality (a mile east of Baker beach) is a light blue fissile schist that contains two minerals, a blue soda-bearing amphibole, undetermined, and minute amounts of lawsonite scattered in the interstices between the amphibole fibres.

Acid Glaucophane Schist.—The more acid schist has the following minerals: glaucophane, a groundmass that is quartz or a mixture of quartz and feldspars, large cubes of pyrite, chlorite, titanite, white mica and a mineral determined as andalusite. The glaucophane is present in large elongated crystals with indefinite end boundaries. The pleochroism is very strong, the section being cut parallel to the direction of schistosity while the blue to violet pleochroism is most common. The quartz or feldspars, without twinning, make up the large part of the rock. This is most likely all quartz, being of a fibrous nature, and the fibres are often much twisted and distorted.

The cubes of pyrite are perfect and have affected the deposition or the recrystallization of the quartz, so that the quartz has formed in fibres, so arranged that they appear attached to the pyrite cubes, with the long axes at right angles to the faces of the cubes.

Chlorite occurs in small yellowish green patches scattered irregularly throughout the quartz, showing anomalous colors under cross nicols.

The titanite is found mainly as small irregular inclusions in the glaucophane, some also being seen in the quartz.

There is some white mica with the quartz. In ordinary light its index of refraction in one direction is nearly the same as that of quartz, but in another position of rotation it shows a slight absorption along the cleavage lines which are parallel to its length. Under cross nicols the colors are high, at least third order, and somewhat irridescent. The last named mineral andalusite, is in radial aggregates with a marked cleavage parallel to the length and slight cróss cleavage. It is nearly colorless in ordinary light and with a relief higher than that of the quartz, but lower than the titanite. In polarized light its colors are low, blue grey of the first order with right angle extinction.

It is worthy of note that though this schist is quite silicious, neither garnets or lawsonite have been developed. If the rock had a soda-bearing feldspar it may be that in the formation of the secondary minerals, after the soda had been removed, the remainder of the feldspar constituents formed this aluminium silicate.

Quartz Glaucophane Schist.—The other schist to be described is a quartzose glaucophane schist from about one mile northeast of Lake Merced. There are three minerals present: quartz, glaucophane, and white mica. The rock shows its nature in the hand specimen, appearing as a hard blue quartzite with a suggestion of schistosity.

The main mass of the rock is recrystallized cloudy quartz with fine aggregate texture.

Fine needles of blue glaucophane appear developed with their long axes parallel to the direction of schistosity. The length of these needles is considerable in proportion to their width. Measurements gave a maximum length observed as .18 mm. with an average of .10 mm. The average thickness was about .01 mm. with a maximum of about .05 mm. This shows that these needles are mostly thinner than ordinary rock section, so that pleochroism and interference colors were, for the most part, much obscured. The pleochroism of this glaucophane was from colorless to violet to blue with an absorption scheme of $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$. The extinction angle $\mathfrak{c} : \mathfrak{c}'$ is quite small, a maximum of 8° being observed. Ilmenite and pyrite are present in very minute cubes. The cloudy appearance of the quartz may be caused by the dissemination of these fine particles of iron throughout.

White mica is present, intergrown with the quartz, and is noticeable by the marked difference of relief in one position of rotation. In polarized light the colors are third order or higher.

Small veins of secondary quartz appear in the section. These show the same aggregate texture and wavy extinction as the other quartz, but may be distinguished in ordinary light by their clear and colorless appearance, as contrasted with the clouded appearance of the quartz of the rock proper. Without exception the size of the individuals of the aggregates is much larger than those of the other quartz. The average size of the grains of quartz in the main rock mass was about .02 mm. in diameter.

Further careful search may reveal schists not mapped, but such areas would not affect the structure of the region as worked out. The relations of the schists and other rocks will be considered further on in the paper.

III. Areal Distribution.

In the areal distribution the geologic order of terranes followed in the descriptive text is not adhered to. The distribution is best

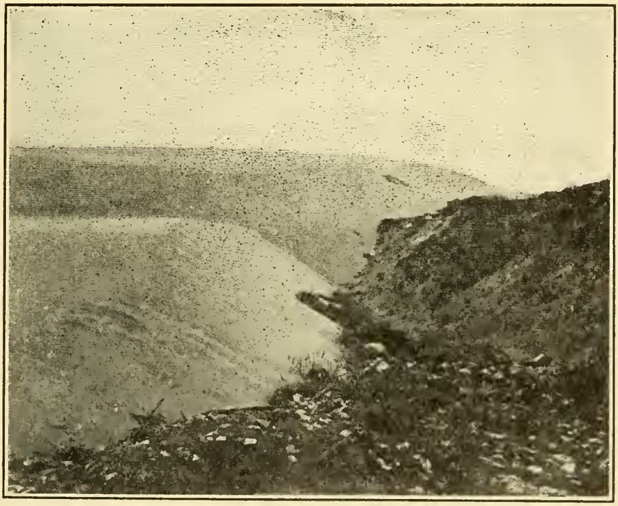


Fig. 9.

Recent sand dunes near Golden Gate Park. These are derived from the Pliocene and Pleistocene deposits.

shown upon a map, and for this purpose a colored map, with necessary legend, is appended.

Merced Series.—The series that deserves first mention here is the Pliocene, Pleistocene and the derivative sand dunes. These cover the largest part of the area mapped, and because of the widespread distribution of the æolian sand, give the area the appearance of hills almost buried by sand.

The Merced series proper is confined to the long low valley lying between the Buri-Buri ridge and San Bruno mountains. The series lies upon the old Franciscan rocks near Mussel Rock and from there rises to the top of Buri-Buri ridge, follows southeast along the trend of the ridge to about two miles northwest of Millbrae, where it drops into the low hills and appears on the low lying hill to about two or three miles southeast of Millbrae. The complete southeast extent of this series is not shown on the map. Below Millbrae the streams have cut through this series exposing the underlying rocks showing that it appears only as a thin edge and that it is probably chiefly wind-blown material.

A point of interest in this connection is the exposure of the Franciscan rocks on the fronts of the steep hills west of Millbrae and of Baden. In the stream bottoms that run between these hills and in the circular-shaped basin behind them the Merced beds are in place.

Going northward along seven mile beach nearly the entire thickness of the series is exposed tilted toward the northeast. Just south of the Life Saving Station the beds disappear under the Pleistocene formation. The northeast line of the contact with Lake Merced to South San Francisco is not exposed, the rest of the eastern contact from South San Francisco to south of Millbrae, is determined by the marsh line. The obscuring of this contact along San Bruno mountains is caused by the Pleistocene materials which have been blown up against San Bruno mountains about to the five hundred foot contour in places. North of San Bruno mountains these sands cover most of the city proper, obscuring the underlying geologic structure in many places. This formation merges into the recent deposits along the flats.

San Bruno Sandstone.—The formation of next importance in distribution is the lowest sandstones and shale beds of the Franciscan series which is represented in San Bruno mountains and which for purposes of differentiation in this paper is called the San Bruno sandstone. It is not definitely known what place this sandstone has in the Franciscan series as compared with the sandstones and shales exposed at San Pedro Point, but it appears as if the lowest part of the mountains exposed at Sierra Point was the equivalent of the middle or upper section at San Pedro.

This sandstone and shale form San Bruno mountains and the parallel ridge northeast of Guadalupe Valley; the hills known as Columbia Heights; University Mound in the southwestern part; and the southwestern part of San Miguel Hills, partly covered by the sands and disappearing under the lower jaspers. This sandstone appears in only one place north of the exposures mentioned, and that is at the Cliff House and around Point Lobos to within about a mile of Lobos Creek.

Jaspers.—The formation that overlies the San Bruno sandstone is the lowest jasper bed. This bed of jasper lies directly upon the San Bruno sandstone along the cliffs north of Golden Gate Cemetery. It disappears under the æolian sands and is exposed in only one or

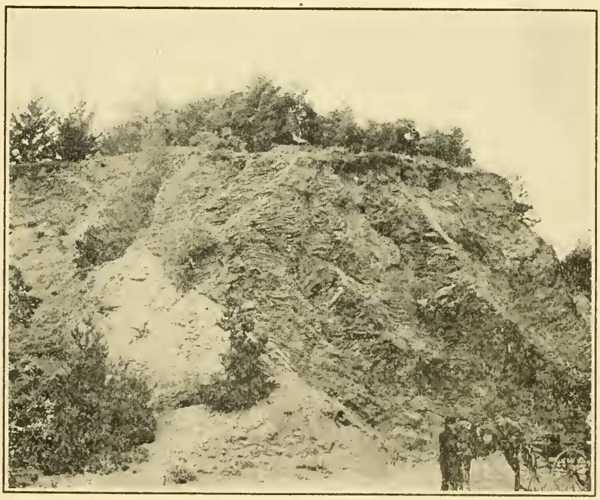


Fig. 10.

Local folding in jasper exposed in a quarry at Golden Gate Park.

two quarries near Point Lobos avenue until Golden Gate Park is reached where it is seen in Strawberry Hill, and one of the smaller hills there that has a wooden cross erected upon it. This jasper forms the crest of the ridge of hills in Sunset district, being exposed only from M to S streets. Continuing, this formation makes up the portion of the San Miguel Hills known as Sunnyside Addition, and extends around the east and north side of those hills almost to Valencia street. On the east side of the railroad tracks it appears in the southwestern part of Holly Park and in irregular areas on the northeastern side of University Mound. On the hills just north of Visitation Valley and west of Railroad avenue the entire thickness of the bed is seen. Two small hills of this jasper occur, one on either side of the entrance to Visitation Valley. Their relations are explained in the discussion of the structure.

Silver Terrace Sandstone.—Lying between the lower and the upper jasper bed is the Silver Terrace sandstone which consists of a bed of sandstone and some tuffs which, together, have a thickness of about five hundred feet. The tracing of the Silver Terrace sandstone and the associated tuff is much more difficult than tracing the jaspers. The full thickness is exposed dipping into the northeast from a point about a half mile east of Lobos Creek to a point about a half mile northeast of Lobos Creek where the upper jasper is exposed in a quarry on the Presido. It is present as an erosion remnant in Golden Gate Cemetery, but does not appear between that place and Blue Mountain. It can be traced around the west and southwest sides of Blue Mountain and Twin Peaks, and it crosses a gap between the latter place and Sunnyside Addition, and continues around the eastern side of Twin Peaks to Buena Vista Park. Erosion remnants cap the hills southeast of Buena Vista Park, Castro street hill and Dolores street hill. In the eastern part of the city it passes through the gap between Bernal Heights and Holly Park and forms the Silver Terrace hills. The sandstone forms a floor upon which rest the Hunter's Point serpentines and the two small hills southwest of Hunter's Point. On top of the serpentine forming Hunter's Point hills, is a small area of conglomerate belonging with this sandstone.

Upper and Lower Jasper Bed.—The Silver Terrace sandstone is overlain in some places by the upper jasper bed, notably at Blue Mountain, Twin Peaks, and at Bernal Heights. It occurs in several places at the Presidio quarry, near Masonic Cemetery, on the extreme end of Hunter's Point.

Telegraph Hill Sandstone.—A sandstone called Telegraph Hill sandstone composes all the hills in the business portion of the city, Russian Hill, Telegraph Hill, Rincon Hill, Lone Mountain, Lafayette Hill, and is exposed beneath the serpentine at the Presidio, and both under and over the serpentine at the Potrero. It does not appear on top of the jasper anywhere in the city except at the Potrero, and nowhere else is its relations to the Franciscan series shown. Elsewhere in California, so far as the writer's observations go, the Cretaceous overlies the jaspers, but there have been no fossils found here to show that this Telegraph Hill sandstone belongs to the Cretaceous, and as it resembles the San Bruno sandstone petrographically and macroscopically, it is regarded as a sandstone belonging to the Franciscan series and overlying the jaspers.

Serpentines.—Across the city in a northwest-southeast direction from the Presidio to the Potrero and Hunter's Point is a line of irregular areas of serpentine. This line of serpentine is geologically continuous, though it does not appear so on account of the intervening sandstones and æolian sands.[1] The proof of this continuity rests upon the field evidence and the petrographic similarity of the serpentine. That from the Potrero was found to be a lhezolite serpentine, while that from the Presidio was found to be a pyroxenite, but, as remarked in the previous discussion of the rocks, the chemical analysis shows that olivine must be present. The Presidio rock must also be a lhezolite serpentine as is that from the Potrero. Chemical analysis would prove this point beyond a doubt. There are a few small areas of serpentine in other places, namely, in the hills at South San Francisco, Buena Vista Park, Castro street hill, Islais Creek near Holly Park, University Mound, and at several other localities.

Igneous Dikes.—The igneous dikes are present as intrusions in the serpentines of the Potrero and Hunter's Point, in the Silver Ter-

[1] Lawson, A. C., Geology of the San Francisco Peninsula. 15th Ann. Rept. U. S. Geological Survey, p. 445.

race sandstones and tuffs, and in the San Bruno sandstone in a number of places. These dikes are on the north side of Visitation Valley, near Railroad avenue, and near the entrance to the valley, and also on the southwestern slope of San Bruno Mountain, and in the little hills in the marsh, one and one half miles south of South San Francisco.

Schists.—The schists of San Francisco come mainly from one area along Golden Gate Strait between Point Lobos and Lobos Creek. The quartzose glaucophane schist described comes from the San Miguel hills about one mile north of Ingleside Race Track. The biotite schist is from just north of the entrance to Visitation Valley.

IV. Structure.

Main Faults.—The structure of San Francisco peninsula is complex but controlled in general by three main faults. The type of structure is the same as that which characterizes other parts of the Coast Ranges. These are dominant fault lines, with a general northwest and southeast trend. Parallel to these faults are the major lines of folding and minor lines of faulting. Making almost a right angle with these lines are the minor lines of folding.

Lone Mountain Fault.—Lone Mountain fault is the first of the three main faults which control the geology and topography of the San Francisco peninsula to be considered, as it crosses the city from the Presidio to Hunter's Point in a straight line. This fault may be seen only in the cliff near the Presidio. The line can be traced across the city only by the topography and by the areal distribution of the rocks. It is this line which determines the northern limits of the jaspers (excepting that at the Potrero), and the southern limit of the Telegraph Hill sandstone. As the jasper does not appear again north of this line, it is believed that the downthrow of this fault is on the northeast. This is also substantiated by the presence of a very closely compressed syncline, with its axes parallel to the fault and apparently developed by the slipping of the fault block. The throw of this fault is not known, but it is judged to be between 800 and 1,000 feet.

San Bruno Fault.—The second fault is the San Bruno fault. This is clearly a thrust fault with the upthrow of perhaps 1,500 feet on the northeast side. It is not quite straight but enters the area on the west between the Ocean House and the Life Saving Station, follows a southeast course swinging slightly toward the north as it

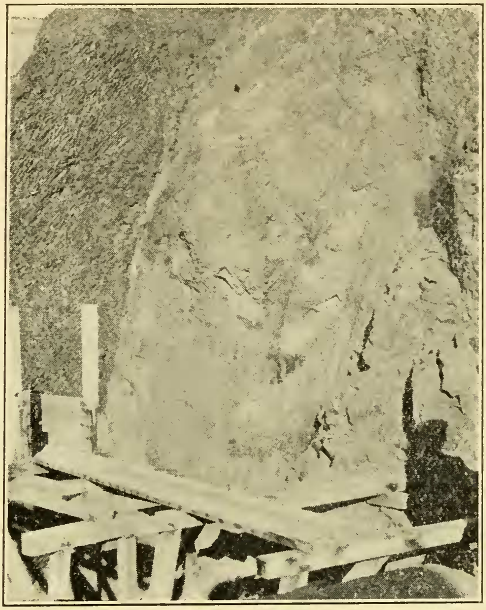


FIG. 11.

Jasper remnant resting against sandstone at the point where the Lone Mountain fault cuts the cliffs near the Presidio.

reaches the bay one half mile north of San Bruno Point. The crescent shape of the San Bruno hills is apparently directly related to the form of this San Bruno fault line.

In connection with the upthrust of the San Bruno block, an anticline has been produced parallel to the axis of the fault. At the point where the railroad turns directly west, leaving the city near Ocean View, a topographic saddle has been formed by the breaking down of this anticline. In places this San Bruno fault distinctly affects the topography: a line of low hills along the southwest side of the ridge have jasper remnants exposed on their summits, showing that they are geologically above the top of the San Bruno mountain. The anticline developed by this fault may be seen quite plainly in two places, near Ocean View and on the bay shore north of San Bruno Point.

San Andreas-Portola Fault.—The most important fault line on the San Francisco Peninsula is the San Andreas Portola fault. It is plainly discernible in the bluffs at Mussel Rock, and from there it runs toward the southeast through San Andreas and Crystal Springs Lakes. This same fault continues to the southeast through the Santa Cruz quadrangle, where it is known as the Portola fault. This is one of the main lines of weakness in the Santa Cruz mountains, and it has been the line of movement at various times. There have been at least two important movements along this fault line,

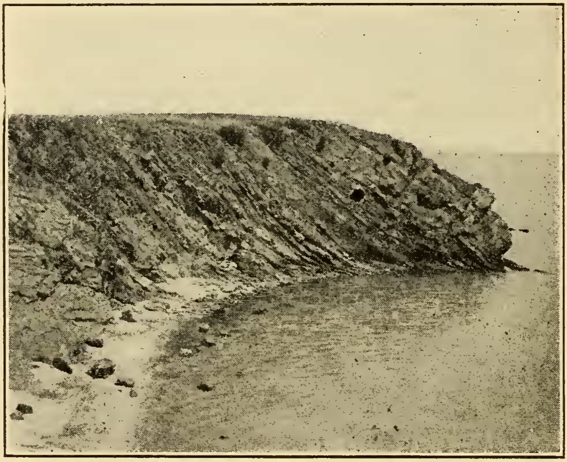


FIG. 12.

A partial view of the anticline at San Bruno Point showing the sandstone and shale beds dipping northeast.

for the Franciscan sandstone lying northeast of the line is geologically higher than that on its southwest side. Since the movement that caused this dislocation of the Franciscan rocks there was another movement after the deposition of the Merced series which resulted in the tipping of the Merced beds toward the northeast. The steepness of the dip of these rocks increases from Lake Merced southward to Mussel Rock. This second movement brought the Franciscan beds on the northeast side into a position but slightly lower than their original one, and there has been an apparent development of a minor syncline on the south side of San Andreas Lake parallel to the fault line in places, while the Franciscan beds on the north side of the lake dip sharply to the southwest. The total throw of this fault is indicated by the amount that Franciscan beds on the northeast side of the fault are lower than those of the same horizon on the southwest side, and that is about 500 feet.

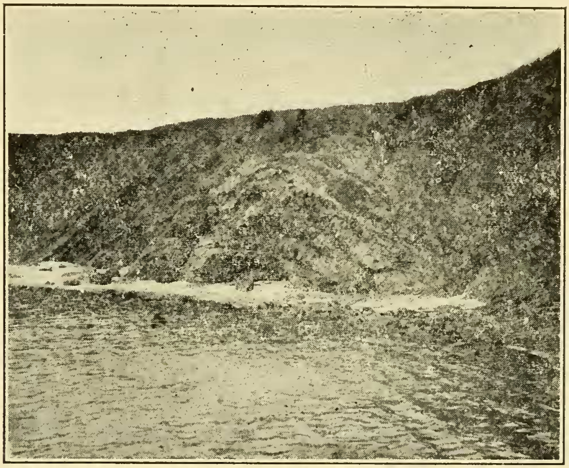


Fig. 13.

The San Bruno anticline exposed in the cliffs one mile north of Point San Bruno.

This displacement has been spoken of here as a single movement, but it must be taken as the algebraic sum of all the movements up to the present time rather than as a single movement. That the upthrow of this fault is on the northeast side is confirmed by the evidence in the Santa Cruz quadrangle where the Franciscan beds in Black Mountain are higher than the Miocene beds southwest of the fault.

Minor Faults.—Of the minor faults there are only two worthy of consideration; these are the Visitation Valley and the Wood's Gulch faults.

Visitation Valley Fault.—There are likewise two minor faults parallel to these main fault lines and possibly a third one. The first of these has resulted in the letting down of the sandstones on the southwest side of the hills known as University Mound, and the formation of Visitation Valley. At the entrance of the valley are two little jasper remnants that have been faulted down. The line of faulting is approximately parallel to Visitation avenue, passing between the two ridges of jasper in the northeastern end of the valley.

Guadalupe Valley is parallel to this line but since it is entirely in San Bruno sandstone it is not certain whether or not its structure is the same as that of Visitation Valley. The dips of the beds on the northeast side of the San Bruno mountains are very much steeper than those on the southwest side of the ridge. This leads to the belief that the Guadalupe is a fault valley, though definite proof has not been found.

Wood Gulch Fault.—In the Merced series about one mile north of Mussel Rock there is another minor fault having a downthrow of some eight hundred feet on the southwest side. There are other small faults in the Merced beds with displacements of twenty-five feet and more, but none of them are important.

The deformation of the Merced beds shows that the San Andreas faults are of post-Pliocene age but the age of the faults across the city of San Francisco from the Presidio to the Portrero (Lone Mt. fault) and at San Bruno Mountain may or may not be of the same age. The greater maturity of the topography in the city hills and on San Bruno Mountain suggests, however, that these faults are both older than the San Andreas-Portola fault.

Folding.—This area has been folded into three blocks which are considered in the order of their importance.

Merced Block.—The area occupied by the Merced beds between Buri-Buri Ridge and San Bruno Mountain is in the form of a slight syncline; this is formed as the result of a block tilted toward the northeast by a thrust fault on the southwest side.

San Bruno Block.—Between San Bruno fault and Lone Mountain fault is the anticlinal fold, already noted and parallel to the San Bruno fault. Otherwise the whole block is simply tilted toward the northeast, the dips becoming steeper shortly before reaching the Lone Mountain fault.

Lone Mountain Block.—North of this fault line the folding is more complex. Parallel to the fault is a closely pressed syncline, called the Lone Mountain syncline, which can be followed from near Thirteenth and Market streets to the Calvary Cemetery, and, judging by the structure exhibited by the sandstone underlying the serpentine at the Presidio, it extends still further. Serpentine is exposed in different places, following the bedding planes of the sandstone, dipping toward the northeast or southwest, according to the side of the synclinal axis that it is on, showing that it is present as a true sill.

Major Folds.—Passing to the northeast of this syncline, the dip of the beds becomes less, averaging about 30° until Lafayette Hill is reached. From there they arch in an anticlinal dome to Russian

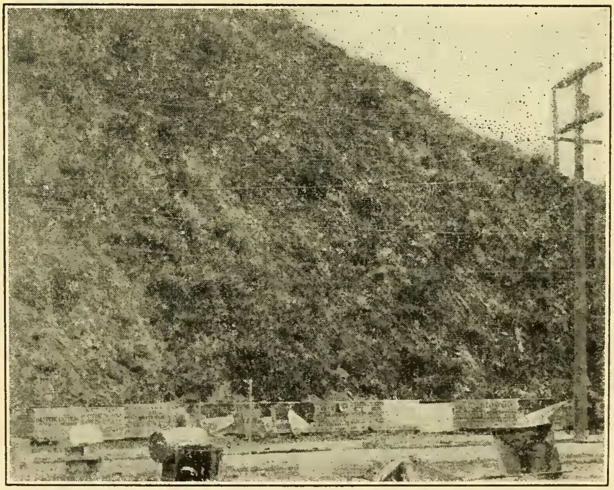


FIG. 14.
Bedding of shale in Telegraph Hill series; the exposure on Second street.

Hill and California Street Hill, in what is called the Lafayette Hill anticline. Between Russian Hill and Telegraph Hill is a syncline, the axis of which is closely followed by Montgomery avenue, which is called the Montgomery avenue syncline.

Minor Folds.—Lines of minor weakness are represented by a syncline through Rincon Hill, called the Rincon Hill syncline, an anticline between the hill at Black Point and Russian Hill, the Black Point anticline, and an anticline between Rincon Hill and California Street Hill, called the Market street anticline. There

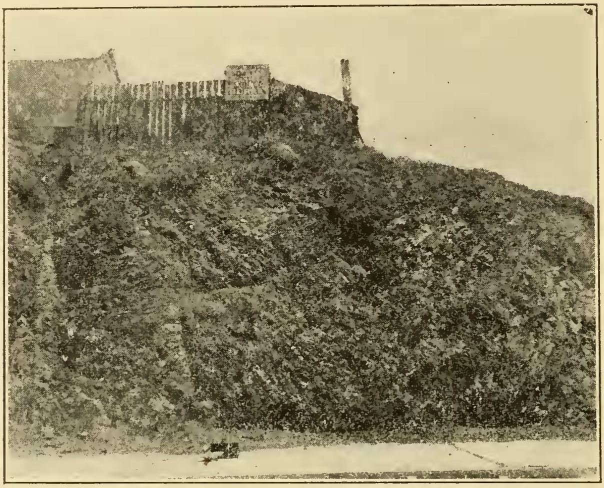


FIG. 15.

Local folding in Telegraph Hill sandstone; exposed in a street out on Jones street, near Vallejo.

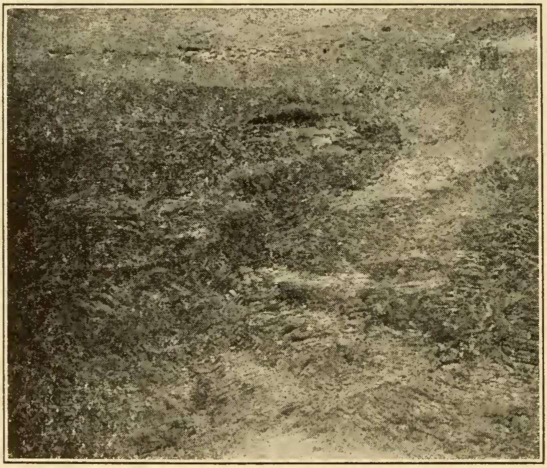


FIG. 16.

Local folding in the jasper beds exposed at Golden Gate Park.

are besides these two small synclines, one of which is exposed at Lombard and Larkin streets, the other on Jones street near Vallejo street.

There are other minor lines of faulting but they are not of enough importance to be mentioned here.

A noticeable feature of the sandstone of the city is their jointing. These joint planes cut the rocks in many directions, without any apparent regularity, giving in exposed places such sharp, pro-

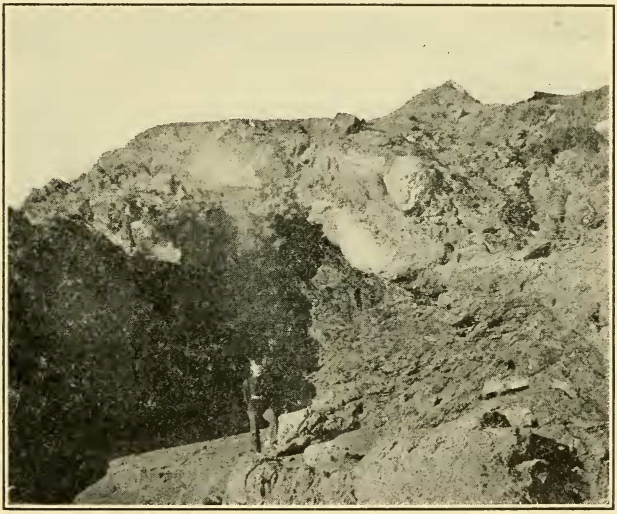


Fig. 17.

Serpentine of the Presidio sill resting upon a sandstone floor.

jecting, triangular faces, as to make it difficult or impossible to distinguish the original bedding planes. The pressure that produced these results in sandstone has not broken the jasper but merely thrown it into complicated folds.

Structure of Serpentine Intrusions.—All the serpentine areas of San Francisco peninsula are in the form of sills. The largest of these is the Presidio, and next are two nearly as large at the Potrero and at Hunter's Point. In the last two areas the hypersthene diabases have been intruded and have been broken up by the movements within the serpentine itself, during the process of hydration.

As a result of this breaking up the diabase outcrops are irregularly scattered through the serpentine areas. The sills at the Presidio and Potrero show the presence of two different serpentine intru-

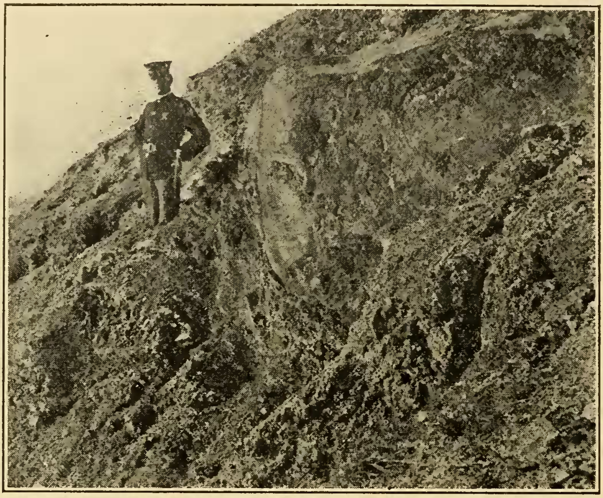


Fig. 18.

A place in the cliffs north of the Presidio where the serpentine is intruded into the shales of the Telegraph Hill beds.

sions; whether they both occurred at the same time or at different times is not clear.

Sections through these different sills show their structural features plainly.

V. Physiography.

The main features of the topography of the northern end of the peninsula are controlled by the major faults, giving as a result two large blocks tilted toward the northeast, and one block with complex folding. The northwest-southeast trend of Buri-Buri ridge, San Bruno Mountain and the line of jasper hills across the city from the Cliff House to Hunter's Point is characteristic of the Coast Range ridges that are determined by major and minor faults and major folds. These features are plainly shown in the accompanying photograph of a relief map of the peninsula made by A. H. Purdue, of Stanford University.

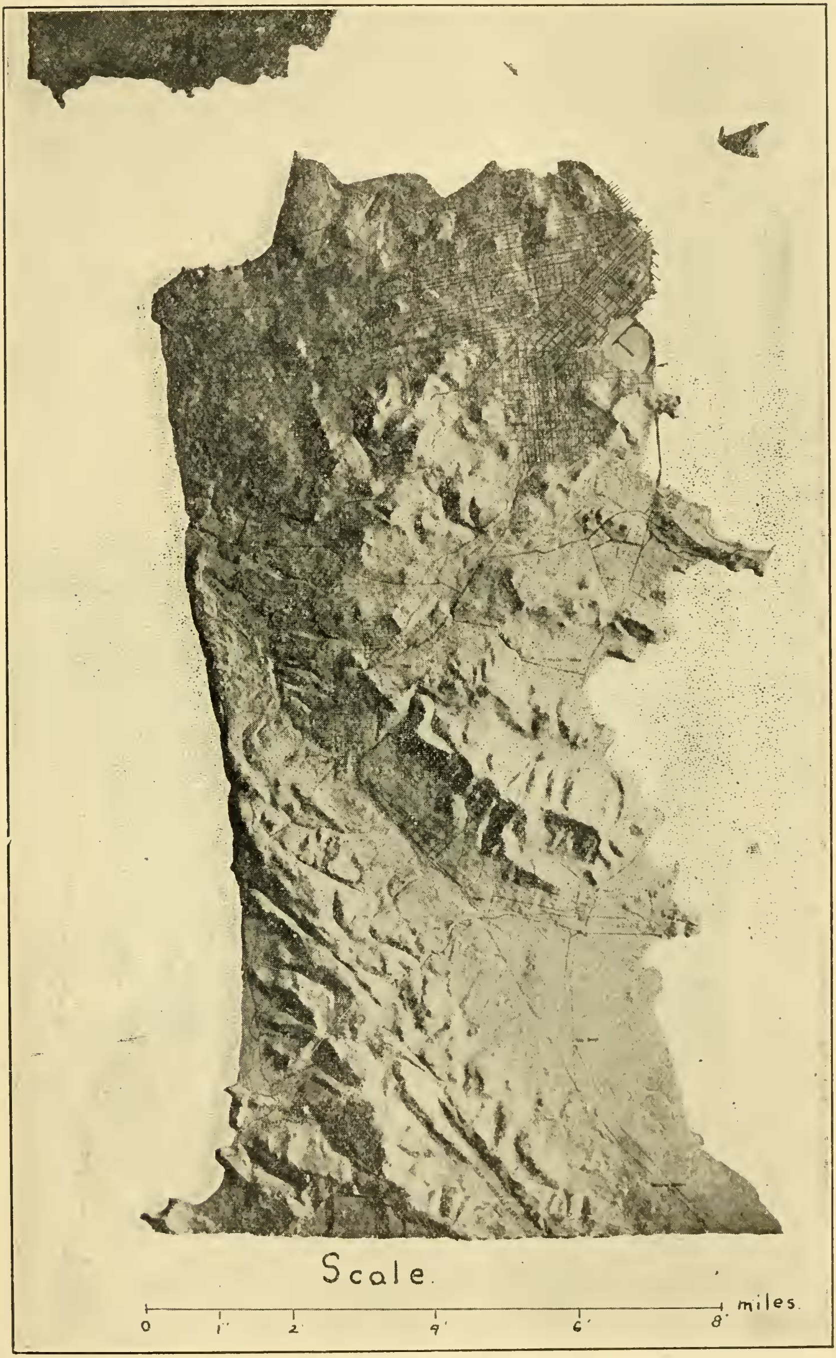


FIG. 19.

Relief Map of San Francisco Peninsula by A. H. Purdue, 1894.

Merced Block.—Without considering the region south of San Andreas Lake in the Merced series, there is a tilted block, with terraces both older and newer than the faulting. This may be regarded as one large block that has many minor faults or smaller blocks of the same type as the large one. The largest of these faults, the one at Wood's Gulch, has determined the stream drainage at that point. Otherwise the drainage of the whole block is toward the northeast, or down the slope of the tilt. These streams have their heads in circular canyons, and which must represent a drainage system older than the Merced formation. The Franciscan series, forming the northeast front of the Buri-Buri ridge, are the cliffs of the pre-Pliocene beach, and the fact that the Merced series rests on the tops of these hills with almost a flat area shows that

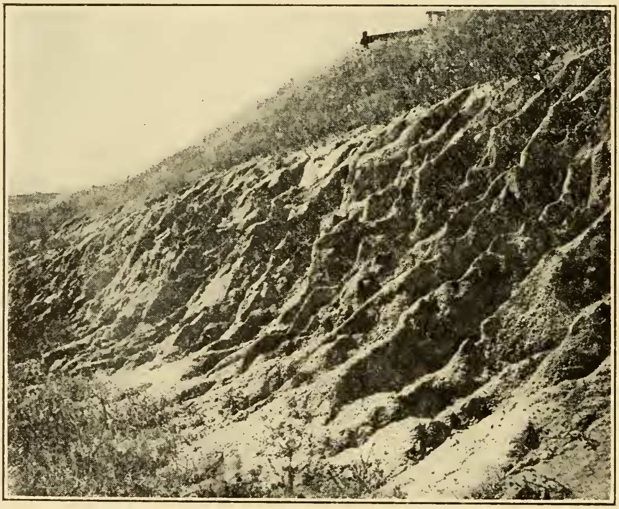


FIG. 20.

A typical form of topography in the beds of the Merced series.

this is a pre-Pliocene terrace. The presence of the Merced series in place in the creeks and between hills of Franciscan sandstone indicates that the present drainage is controlled by the older drainage, the existing streams running down the submerged valleys of pre-Pliocene times.

Drainage.—The long, low valley between Buri-Buri ridge and San Bruno ridge is a slight syncline, the form of which is determined by the thrust block on the southwest side. It may have been the formation of this syncline that has controlled the drainage of the stream that once flowed through the basin now occupied by Lake Merced. This lake has been formed by the damming of the stream's mouth by a barrier beach; the bottom of the lake is now about ten feet below sea level.

San Bruno Block.—The physiography of the San Bruno block is apparently older than that of the Merced block and is determined mainly by structure.

Effect of Structure.—The next feature of note is the San Bruno thrust block. Along the southwestern side of the San Bruno range is a ridge of low hills capped with jasper. In the geological column these are probably within a few hundred feet vertically of the jaspers represented on Buri-Buri ridge. As these jaspers dip toward the southwest while those on Buri-Buri ridge (except near the fault zone) appear to dip toward the northeast there is the suggestion of a pre-Pliocene syncline, whose eroded trough has been the place of deposition of the Merced series. If the San Bruno fault is pre-Pliocene, as it seems to be, then the valley in which the Merced was deposited was an eroded syncline between fault blocks. The greater age of the San Bruno fault is shown by the more mature topography of that range as compared with the Buri-Buri country.

With one exception the streams of the San Bruno block drain northeast or southwest. In this exceptional case the stream turns at a right angle from a northeast direction and flows southwestward along the northeast side of the San Bruno mountains in a direct line with the Guadalupe Valley. The direction taken by this stream lends color to the suggestion that the Guadalupe Valley is a minor fault valley like Visitation Valley.

Drainage.—The anticline in the southwest edge of the San Bruno mountains shows its effect upon the topography at Ocean View where it has broken down. Heading near Ocean View is Islais Creek which runs by an indirect line to empty into the bay south of the Potrero. The drainage of this stream must have been guided by some previous topographic features that are not now evident, though it follows the general northeast trend of the other streams. It is at present slowly filling the basin between the Potrero and Hunter's Point.

The hills through the center of San Francisco, at Golden Gate Cemetery, Strawberry Hill, San Miguel Hills, Bernal Heights and University Mound, owe their prominence to the large beds of jaspers that compose the major part of them. This jasper does not weather like a sandstone, but only breaks down slowly by mechanical means. The canyon through Almshouse tract, with its feeding streams, and the gap through Twin Peaks and Sunnyside addition are formed by the more rapid disintegration of the Silver Terrace sandstone than of the jaspers. The topography of this area in the heart of the city is controlled partly by the jaspers and serpentines and partly by the structure.

Lone Mountain Block.

Effect of Jaspers.—There is a low divide caused by the Lone Mountain fault crossing San Francisco from a point just northeast of Lobos Creek past Lone Mountain, to Hunter's Point. Parallel to this is a line of hills on which the cemeteries are located and Lone Mountain which have survived erosion because of their synclinal structure and the serpentine areas that have helped resist rapid weathering.

Effect of Serpentines.—The Presidio, Potrero, and Hunter's Point remain as noticeable features not because of the slowness with which serpentine alters, but because of the slowness with which it breaks down and is carried off by erosion. The reason the upper beds of sandstones and jaspers do not remain in places over these sills is because the large amount of movement that has taken place has so broken and crushed the overlying sandstone that erosion has been greatly facilitated.

Two small hills, one at Silver Terrace, and the other one and three quarter miles south of South San Francisco, owe their topographic relief to the intrusion of igneous rocks that have metamorphosed the tufaceous materials present to hard resisting greenstone.

Effect of Structure.—The divide between Lafayette and Russian hills and Black Point and Russian Hill represents broken down anticlines while that between Russian and Telegraph hills along Montgomery avenue is a synclinal trough.

The flat in the business portion of the city with its sands and mud obscures the structure of the gap between California street hill and Rincon Hill. Rincon Hill being folded in a syncline parallel to the minor lines of folding, has the dip of the beds in a different plane from the dip of California Hill beds. The apparent solution is that Market street has been the direction of drainage of a stream passing between the two hills, through an eroded anticline.

There are no streams now draining this flat but if there were their drainage would be northwest-southeast along the axes of folding and at right angles to the direction of the streams on the tilted blocks.

The series of elevations and depressions to which this area has been subjected have not all left traces upon it. Various places around the bay show an old raised shore line. There are two terraces along Buri-Buri ridge—one at an elevation just a little above the floor of Merced Valley, the other at an elevation of five hundred feet. This last one is the pre-Pliocene terrace previously mentioned.[1]

VI. General Discussion.

Age of the Franciscan Series.—The age of the Franciscan series is not definitely and directly known from paleontological evidence, but must be arrived at indirectly by the age of the superimposed beds. The Franciscan series of sandstones and jaspers is very much broken up, metamorphosed and silicified by the dynamic movements through which it has passed. By this and by its constant macroscopic and petrographic characters it may almost always be recognized.

The conclusions of Dr. Fairbanks and Dr. Becker from their

[1] Lawson, A. C., Geology of the San Francisco peninsula. 15th Ann. Rept. U. S. Geological Survey, p. 464.

G. H. Ashley, Neocene Stratigraphy of Santa Cruz Mountains, Proc. Cal. Acad. Sci., Series 2, V, 354.

A. C. Lawson, Geomorphogeny of the Coast of Northern California, Bull. Dept. Geology University California, I, No. 8, p. 241.

work on the Franciscan series, are, that it is at least pre-Cretaceous in age, but how much older, is as yet unknown.[1]

Formation of the Merced Series.—The mode of formation of the Merced series seems from all the field evidence to have been a local deposition in an arm of the sea, or an outlet to the bay corresponding to the present Golden Gate. In the area south of this are large deposits of fresh water gravels that are considered by Dr. Arnold to be the fresh water equivalent of the Merced series. If this is true and these fresh water gravels represent a fresh water lake which emptied into the Pacific Ocean by way of the Merced outlet, then there should be faunal evidence of the change from fresh to salt water forms. Work of the nature that would demonstrate the plausibility of this theory has never been attempted. There remains, however, the conclusion that this great thickness of Pliocene beds exposed at Seven Mile beach is a local deposit formed in one of the two ways suggested and undoubtedly not extending in any such thickness over the main San Francisco Peninsula.

Origin of the Jaspers.—The Franciscan jasper was considered by Becker as metamorphosed silicious shale,[2] and by Lawson as a deposit from submarine springs.[3] The wide spread extent of the beds shows it to be a true bedded deposit, as it is known to extend from near the Oregon line to Santa Barbara county.

The presence of radiolarian remains in the jasper also show it to be a marine deposit. These fossils do not prove that the jaspers are composed of radiolaria but show that it is similar to present-day deep sea deposits. The agencies that have metamorphosed the sandstones have probably helped in the secondary silicification of the jaspers.

There is another possible origin for the large beds of jaspers in the Franciscan series and this is suggested by similar beds in later deposits. The siliceous Miocene shales resemble very closely the jasper beds under discussion except that they do not show so much folding and distortion. These Miocene shales are diatomaceous

[1] The Pre-Cretaceous Age of the Metamorphic Rocks of the California Coast Ranges, American Geologist, IX, 153. Monograph XIII, U. S. Geological Survey, p. 211.

[2] Monograph XIII, U. S. Geological Survey, p. 106.

[3] A. C. Lawson, 15th Ann. Report U. S. Geological Survey, p. 440.

deep sea deposits, altered since the time of their deposition. It is reasonable to assume that the older jasper beds may have been formed similarly to those of the Miocene age whose origin is known.

The fact that remains of diatoms do not show in slides of the jaspers does not prove that they were not there originally. These jaspers are mostly amorphous silica and must have passed through a stage of solution and re-deposition from their original form so that all traces of diatoms might easily be lost.

This hypothesis is worthy of consideration because of the large deposits of siliceous shale that we have in California; and it is more reasonable to consider the older jaspers formed after the same method of later shales, than to assume a different set of conditions and different organisms to have existed without any definite proof. The presence of radiolaria does not affect this either way because small amounts of any organism might be present with the diatoms and have their skeletons preserved.

The fact that in San Francisco we have a lignite and tuffs interbedded with the jaspers is significant. This lignite and tuff show conditions different from those under which the jaspers were deposited. The jaspers represent deep sea or at least quiet water conditions. The presence of lignite shows land conditions, while the jasper pebbles in the sandstone show that the Franciscan area was above the sea and that erosion had set in.

The tuffs present may mean that a period of volcanic activity was the cause of the change in the conditions under which the jaspers were being deposited and a return to land conditions as shown by the lignites. In this same sandstone are large and small pieces of shale, that resemble the shale of the series of rocks underlying the jaspers. This suggests that erosion went through the entire jasper bed and well down into the San Bruno series. There must be somewhere then, an unconformity in the series itself. The extent of this erosion interval is not known nor its place except that one area out of water must have been near the present city, as the pebbles are large and subangular. The second large bed of jasper shows the return of conditions favorable for the deposition of jasper.

Work through the area south of San Andreas lake and over the Santa Cruz quadrangle shows that the jaspers have been removed from the southwest side of the San Andreas-Stevens Creek fault line but that remnants are still preserved on the northeast side. There is the possibility that the first movement along this fault line occurred at the time represented by the unconformity shown by the pebbles in the Silver Terrace sandstone. The area containing the unconformity is on the southeast side of this fault line, but the removal of the jaspers may be due to the erosion of the hills southwest of the fault during Pliocene times.

After the deposition of the jaspers conditions changed and the sandstones were deposited that appear in the northern end of the peninsula. The writer feels fairly sure that he has seen this Silver Terrace sandstone in other localities with the jaspers. Dr. Becker asserts that the granites underlie the Franciscan Coast Ranges. Then if this uplift took place, as suggested during the period of deposition of Silver Terrace sandstone the erosion would be greater in the Santa Cruz mountains on the southwest side of the San Andreas-Stevens Creek fault and would account for the appearance of the Montara and Ben Lomond granites.

Besides the large areas of jasper, there are small areas in various places throughout the Coast Ranges that do not seem to belong to the main beds. These may possibly be erosion remnants left by the removal of the larger masses, or it may be that the organisms forming the jaspers survive in colonies that form small lens-shaped masses. This latter suggestion receives support by evidence found at a place in the cliffs near Golden Gate Strait, where about six or eight inches of jasper appears in the sandstone several feet below the bottom jasper beds. The small bed appears to show the arrival of the first condition that allowed the development of the organisms followed by a period of slight change with sandstone and final settling to the quiet conditions in which the larger deposits were laid down.

The writer is of the opinion that both of these conditions may be found in any area where the jaspers occur.

Origin of the Serpentines.—The field evidence in San Francisco shows that the serpentines are formed by the alteration of olivine and pyroxene-bearing rocks. The large number of exposures has allowed the collection of an abundance of fresh specimens of the rock. In the first part of the paper the petrography of these serpentines was given. There can be little doubt but that the serpentines elsewhere in California are of the same origin as these in this area; that is an alteration from olivine and pyroxene-bearing rock. Field observations at New Idria quicksilver mine and other places confirm this opinion.

The age of the serpentine intrusions on the San Francisco peninsula is not determinable, but field evidence elsewhere shows their age to be post-Knoxville and pre-Chico. In his work in the Coast Ranges Dr. Becker reports finding serpentine boulders in the bottom of the Chico,[1] which makes them pre-Chico. Dr. Fairbanks reports that on Grindstone Creek, Colusa county, the Knoxville shales have been metamorphosed for some distance by the intruded serpentine making the age post-Knoxville.[2] He also thinks that the unconformity between Knoxville and Chico may be due, in part, to the movements caused by the intrusion of these peridotite masses.

Origin of the Schists.—Whether the schists of the Coast Ranges are due to contact or regional metamorphism is a question that is still open. There is no evidence in the schists of the peninsula to prove this point definitely one way or the other. The schists occur both with and away from the serpentines. The quartzose glaucophane schist, described earlier in the paper, seems a result of dynamic rather than of contact metamorphism.

In connection with the formation of schists from contact with serpentines it may be said that the fact that sandstone taken from contact with the serpentine shows no noticeable metamorphism indicating that the action of the serpentine is not very great. If the schists were formed by regional metamorphism they might be formed along lines which would then be the places where the serpentines could be most easily intruded.

VII. The Earthquake of April 18, 1906.

Since the preparation of this paper there has occurred in California, and especially in this district, a seismic disturbance of unusual violence, resulting in the destruction of much property and a

[1] Monograph XIII, U. S. Geological Survey, p. 186.

[2] Fairbanks, American Geologist, IX, p. 161.

small loss of life. Inasmuch as this area is directly affected, a few remarks, of a general nature, are appended regarding the relations of the general geologic structure to the earthquake.

Relations to Structure.—As shown in the chapter on structure the northern end of the peninsula has its main features determined by three faults. The largest of these is the San Andreas-Portola fault which is one of the main lines of weakness in the Coast Ranges. The earthquake is supposed to have been caused by the movement along this old fault line. This disturbance was felt violently from Eureka, in northern California, to southern San Benito county. This is along the northwest-southeast line of valleys, continuous with Santa Clara Valley. Parallel to the fault zone the many towns in these valleys seem to have felt the earthquake with approximately equal intensities. Crossing the fault zone, at right angles, in a northeast direction, there seems some slight movement along a parallel line of weakness passing down through San Francisco Bay by Alviso, and southeastward, but there is no plain proof of this movement. The intensity decreases rapidly, going eastward from the fault, toward the San Joaquin Valley.

Movement along the San Andreas-Portola Fault.—The movement along the San Andreas-Portola fault line is quite apparent and consists of a thrust of the Merced block from three to eight feet toward the southeast, along the direction of the fault, with a slight downthrow, perhaps an average of twelve inches on the southwest, the first movement being the more important.

Intensity.—In San Francisco the general intensity was slightly less than that in some of the smaller towns near by. Substantial structures in that city were only slightly injured, broken chimneys and small cracks being the usual destruction. A considerable number of old and poorly made buildings fell with a slight loss of life compared with the population of San Francisco. The small number of deaths, however, was due to the hour at which it occurred. Disastrous fires broke out immediately and caused loss of life much larger than would have resulted from the earthquake, and with a loss of property that was excessively large in proportion to the damage done by the earthquake.

Effect.—In certain localities, between Lafayette Hill and the cemeteries, on the north side of Russian Hill, in the district south of Market and in Mission valley near Eighteenth street, the intensity seems to have been greater than in other places through the city. Houses were completely demolished, car tracks twisted and broken, and water pipes bent.

Relations to Soil and Rocks.—In the first two districts mentioned the damage is due to the settling and sliding of sand on the hillsides. This is best shown near Steiner and Union streets, where crescent-shaped cracks appear in the street. In one place a house set on the hillside moved forward, down hill onto the sidewalk.

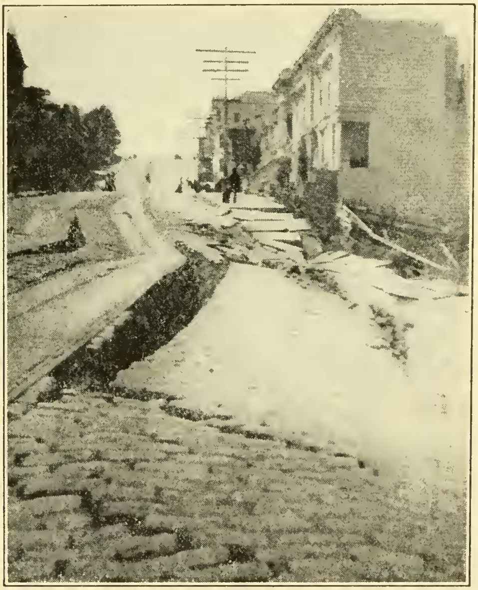


FIG. 21.

Union street near Steiner, showing the effect of a landslide caused by the earthquake.

In the other areas the buildings damaged stood mainly upon filled ground or recently formed loosely set soil. On Valencia street, where the greatest damage was done, a hotel that sank into the ground was upon material that had filled an old creek channel. The area directly around was also intensely disturbed, due, perhaps, to the loosening of the soil by the circulation of waters made necessary by the filling of the old stream channel. The area on Howard street shows merely what happens when houses are on a landslide, as this is nothing more or less than a small, low angle landslide. These low angle slides are common in the soft Merced beds and at one place, near Mt. Olivet Cemetery, the soft wet æolian sand flowed several hundred yards down hill at a low angle, damaging the power house and carrying a lumber pile along with it. It is evident that the places that suffered most were those that stood upon loose sands or soils.

Other districts on the Franciscan rocks did not suffer so much and two areas especially, the Potrero and the Presidio, though offering no large buildings for comparison, seem to have suffered least. It is supposed that the reason for this is that the serpentine, with its many slickensided faces, has taken up a large part of the movement.

Along the San Andreas-Portola fault line the fissure formed by the movement may be seen plainly until it reaches the serpentine of Las Pulgas sill, where it almost disappears, but reappears plainly upon the southeast side of the serpentine. This fault line along which the movement took place in causing the earthquake may be plainly traced from Mussel Rock to Spring Valley lakes at Crystal Springs and on toward the southeast. It has the appearance of an irregular plowed furrow with occasional side furrows. The general downthrow cannot be observed continuously and persistently, but occasionally local variations of even as much as four or five feet occur, crevices being opened from a few inches to a few feet in one spot. The lateral thrust is not always apparent on the ground, but it may be clearly seen in the broken and offset fences across the fault. Various measurements of the slippage gave an average of three feet, but as much as eight and a half feet has been found near Woodside, San Mateo County.

Movements Along the San Bruno and Lone Mountain Faults.— The other two fault zones of the San Francisco peninsula, the Lone Mountain and San Bruno faults, show no discernible movement, and the intensity in the city of San Francisco shows no relation to these or any other structural features. In the area mapped the part that seems to have suffered most is in the soft Merced beds near Baden. The cemeteries just north of that place show considerable evidence of the intensity of the shock. Holy Cross Cemetery suffered most, as much as seventy per cent. of the monuments having been overthrown, while many others turned or slid upon

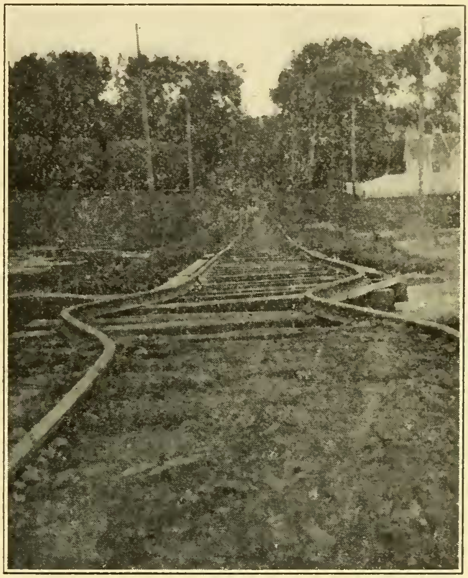


Fig. 22.

A bend in the tracks of the South San Francisco car line near Baden.

their bases. Most of the monuments overthrown fell in a northwest or southeast direction and those that were twisted moved toward the southeast. All have not fallen in these directions, however, for the remaining fallen monuments lay in almost every possible direction.

Local differences in intensity are common and are shown, for example, by the fact that without any apparent reason Cypress Lawn had but a slight loss in comparison with Holy Cross Cemetery, which adjoins it, and which has the same soil.

At South San Francisco, several miles east of Baden, the movement does not show the same intensity as is seen in the Merced Valley. This is especially noticeable from the fact that the six or seven brick chimneys were not thrown down, though some of them were cracked. These are within a very short distance of the San Bruno fault zone, and had there been any movement along that fault the intensity at South San Francisco would have been much greater.

The beds of the Merced series near and north of Mussel Rock are cracked, fissured and faulted in every direction. The Pliocene section along Seven Mile beach has been so altered by landslides

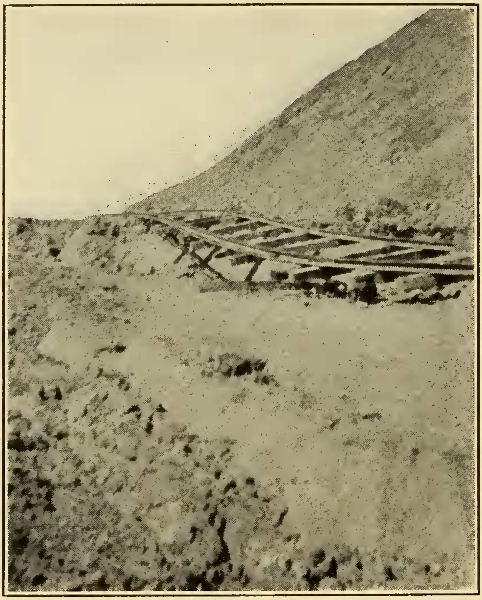
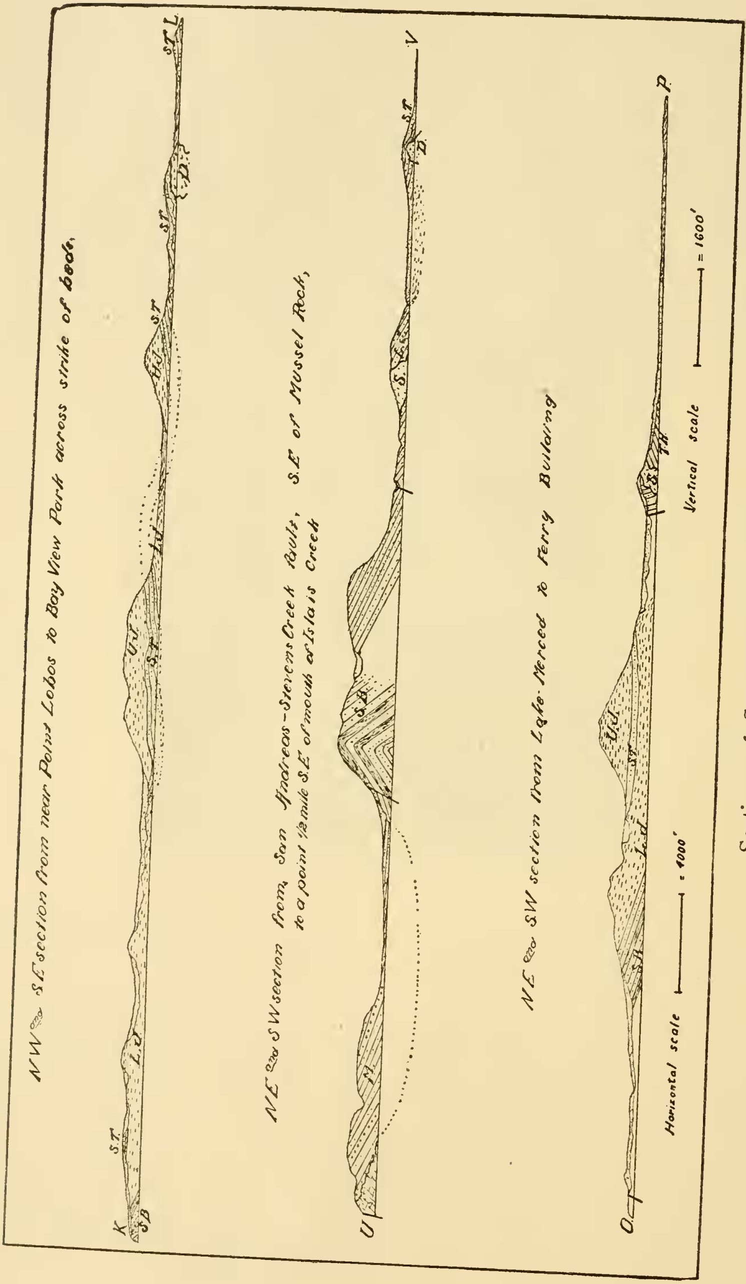


FIG. 23.

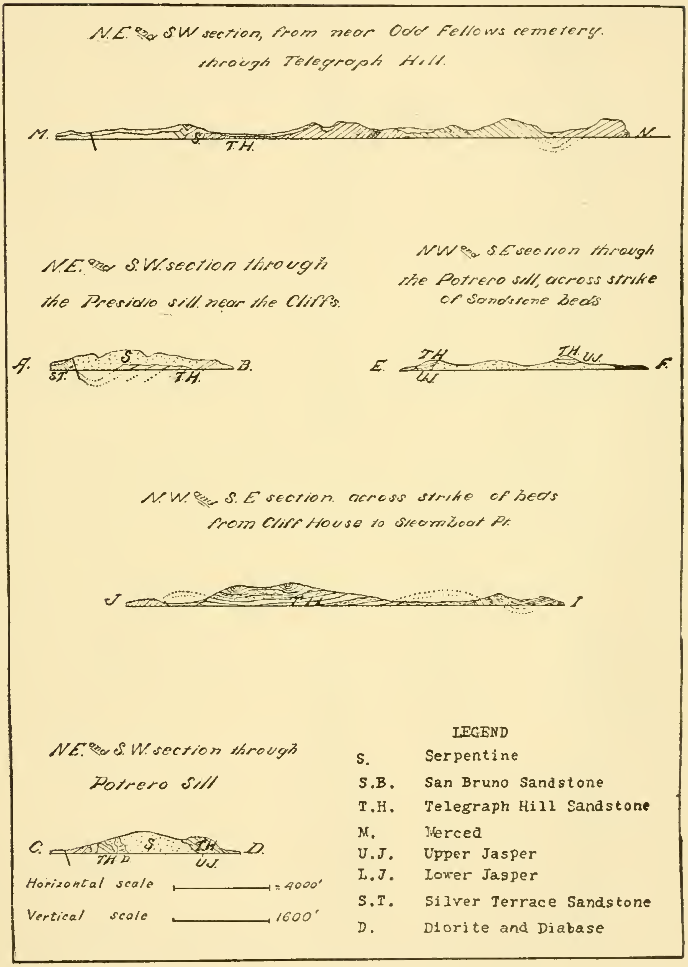
Effect of the earthquake along the road bed of the Ocean Shore Railway; three miles north of Mussel Rock.

that it is hardly to be recognized. There is a tendency here for everything to slide into the ocean, even as far as four or five hundred feet from the cliff's edge. The road bed of the Ocean Shore electric railway line was seriously damaged along this bluff. Through Wood's Gulch and southeast of there along the fault line, landslides occur on both sides of the canyon, and long cracks cut across the hills just above the Chinese cemetery, showing that this fault is directly related to the main fault and probably formed at the same time. The cracks in the hills southwest of the Chinese cemetery are almost in a direct line with the fault and may indicate a slight movement. The fact that these cracks are not continuous, so that they may be easily traced through Wood's Gulch to the ocean, leads to the belief that they are merely due to the settling or to the beginning of large landslides on the hill tops.

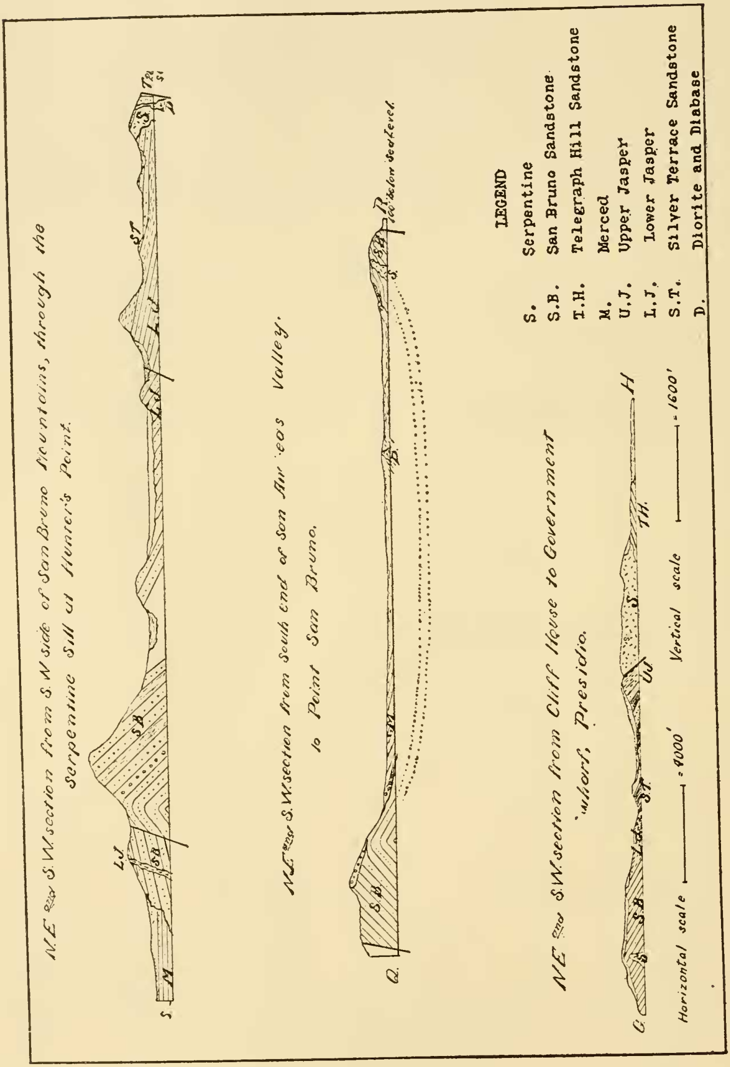
Movements of the adjoining Blocks.—The southwest side of the main fault line seems to be almost entirely free from cracks and fissures, though there are many and large landslides. The general evidence is that the intensity on this southwest side of the fissure zone was about the same as it was on the northeast side.



Sections of San Francisco Peninsula.



Sections of San Francisco Peninsula.



Sections of San Francisco Peninsula.